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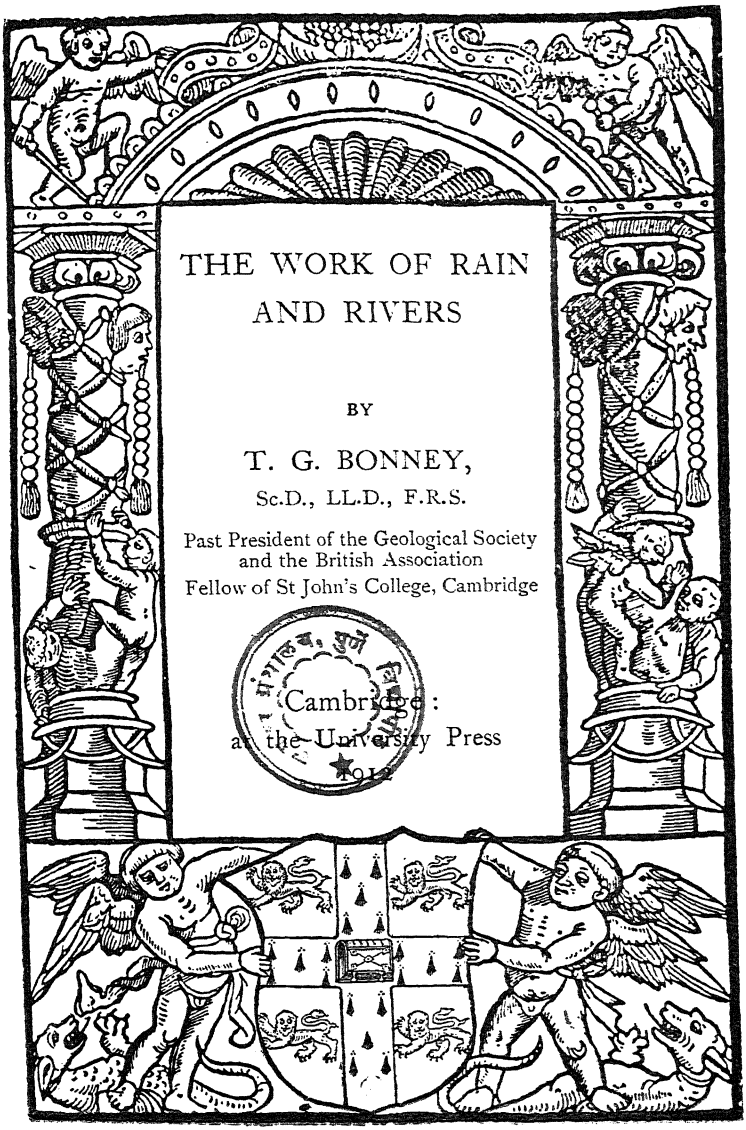
THE WORK OF RAIN AND RIVERS

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THE WORK OF RAIN AND RIVERS

BY

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PREFACE

SO much has been written during the last forty years on the work of rain and rivers, that the author of a brief account of this subject cannot hope to give any new information. But he may do a real service to persons of ordinary education if he can indicate, in language intelligible to them, the methods of observing, the processes of reasoning, and the conclusions reached by trained students of science; for the leading principles in this branch of Geology are not difficult to understand, and the application of them to the interpretation of scenery is an endless source of pleasure. Thus in these pages, the writer has avoided, so far as is possible, the use of technical terms and the discussion of controversial points, and has kept in view, not the student preparing for an examination, but one of the above-named class, and will be amply satisfied if only he can help such a person to understand better and regard with deeper interest the earth on which we live.

T. G. B.

CAMBRIDGE,
July 1912

LITERATURE

References to papers (and occasionally books) on special points in the general subject are made at the foot of the pages where these are noticed. The following list contains the titles of some treatises in the English language where the subject is dealt with more comprehensively.

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The Reports of the Geological Survey of America contain several important and well-illustrated essays, to which occasional reference has been made in this volume, and not a few valuable papers have appeared in the Quarterly Journal of the Geological Society of London. But of late years, in the author's opinion, geologists in North America and the younger school of them in England have often manifested a tendency to exaggerate the effects produced by glaciers and ice-sheets.

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Figures 1, 2, 3, 7, and 9 are reproduced from photographs by Dr Tempest Anderson, to whom I am much indebted for the opportunity of using them. I have also to thank the Council of the Geological Society for the clichés of figures 5 and 6, from blocks used in the volume of the journal of that Society for 1871. These two and the outlines in figures 4, 12, 13, and 17 are from my own rough sketches. Figs. 11, 14, 15, 16, 18, and 19 are reproduced from various volumes of the *Cambridge County Geographies.*

T. G. B.

CHAPTER I

CARVING AND CARRYING

To destroy, to transport and to deposit is the work of rain and rivers. A stream, which has been running clear during prolonged fine weather, becomes turbid after heavy rain. If a glass vessel be filled from it and allowed to stand, the water becomes clean and a fine mud settles at the bottom. What is the source of the sediment? In part it may have been removed directly from the bed of the stream, but we soon see that there is more than this could supply, and that it must have been derived from a larger area. Again, if some gravel be heaped on a pavement we see that after a heavy shower a thin film of fine earth has trespassed on the flags. In like way, all the ground sloping towards a brook or river sooner or later sends material to discolour its waters: thus we suspect, and further examination, as we shall endeavour to show, changes suspicion into conviction, that water is one of nature's carving tools, very probably the most important. In the case just mentioned its action is mechanical, but it can also

WITHDRAWN

be chemical. In a limestone quarry which has been deserted for many years the collector of fossils generally finds old débris to be his best hunting ground. Here the fossils are often developed, that is cleared from the enveloping matrix, with a delicacy and precision, which the most skilled workman can seldom rival. Changes of temperature, which break the continuity of particles by expansion and contraction, and the wind which blows them away, may have done something, but these alone are inadequate. Another agent must have been at work, and that it is the more potent soon becomes obvious. Go where we will over a limestone district, we find its fossils have been similarly developed, while this process is much less conspicuous where the rocks are mainly siliceous—hard sandstones and the like. Such a development does, indeed, take place in rocks other than limestones, but the process is a much slower one. In ascending Snowdon from Llanberis we pass, on the ridge of Llechog, by an old felsitic lava flow, a relic of a volcano of which the present mountain is a fragment. A piece of this ancient lava, broken away from some depth below the surface, is greenish grey in colour and all but compact in structure. The utmost we can detect, after a careful scrutiny, is a very faint indication of some thin streaks slightly paler in tint than the rest of the stones. But if we examine a surface which has been for many years

exposed to the weather, it shows a series of almost parallel whitish bands, about a tenth of an inch wide, running with slight and variable undulations, and rising for a rather less distance above depressions which are generally slightly darker in colour and perhaps a little broader. This recalls to an experienced eye the 'fluxion structure' often seen in a glassy lava, and of such it is undoubtedly a record. If, again, we examine one of those ancient volcanic breccias, which, through lapse of time, has become almost as solid as an actual lava, we find that on a specimen quarried from deep in the mass we can barely distinguish the original fragments, but that on an ancient surface they stand out more or less prominently. As homogeneous lava they would no doubt resist the continuous tapping of the raindrops better than the more heterogeneous ash which cements them, and, for the same reason, would be less exposed to chemical corrosion, which must have also played an important part in this development.

Proofs of a similar action may be found in other hill regions. To many more than Devonians, the Tors of Dartmoor are familiar—those granite crags which rise, like ruinous fortresses, above the wild rocky moorland. A nearer approach shows them to be built up of blocks which, like hassocks, are rounded at edges and corners. The same structure is also seen in the Cornish cliffs about the Land's End. One

of them, in which the horizontal joints are nearer together than the vertical, presents not a little resemblance to a wall constructed with pillows. But if we examine the granite in less exposed situations, or where quarries have cut deep down into the mass, we see that the joints divide it into blocks, rectangular in shape, and as their surface becomes exposed to the sky, we can trace a gradual transition from the prismatic to the rounded outline. In the latter case we can also obtain additional evidence from the surface itself. This in a quarry is comparatively smooth, but the blocks of the Tor or cliff are rough, the grains of quartz projecting above those of felspar, which are obviously more or less decomposed. We cannot doubt that this structure also is the work of the weather; the rain, aided by changes of temperature, having slowly corroded the parts most exposed to its action.

In Cornwall, more especially, confirmatory evidence, indirect but convincing to geologists, may often be obtained. In the neighbourhood of the Land's End, we find the granite moorland strewn with fragments of a rock, so thickly speckled with black as to be distinguished at a glance from that on which it is lying. This rock is formed of two minerals, quartz and schorl[1], both very durable. But we find,

[1] Schorl is the name often given to a black tourmaline.

on farther investigation, that it occurs in veins, often a few inches in thickness, traversing the granite; from which indeed it has been formed, by the subterranean action of water charged with acids; a process, however, which we will not claim for either rain or rivers, because we should find it difficult to prove that this water had its origin in the atmosphere. But the rain, with other atmospheric action, has detached the schorl-rock from the granite, having eaten this away, as already described, and left the other lying upon its surface. The flints, which are scattered over the chalk downs in some parts of south-eastern England, tell a similar tale. Once they were embedded in the soft limestone, as we can see in almost any pit, but they are now left behind as the insoluble residue of a mass, probably once many feet in thickness, which has been removed by the corrosive action of water even more completely than in the case of the granite.

But another common instance, though less direct, is perhaps even more conclusive—that of springs in a limestone district. In some gardens near Wells Cathedral are ponds fed by springs, which spout up so strongly as to form low domes on the surface of the water. This water, as everyone will tell you, contains much carbonate of lime in solution. We cannot suppose it to be supplied from some subterranean factory, so it must have fallen somewhere from the sky and have made its way underground;

it must also have begun its journey at a higher level, since it evidently is forced up rather than leaks out. But 'Wells,' to quote E. A. Freeman's phrase, 'crouches at the foot of Mendips' and the Mendip Hills are limestone. The well-known Cheddar caves, with their pendent stalactites, are further proofs of this action, and a most remarkable one was obtained about two miles from Wells some fifty years ago. Close to Wookey Hole, noted for its remains of hyaenas and other animals long extinct in Great Britain, a limpid stream issues from a cave and flows through the meadows. Without any obvious reason the cattle grazing in them began to sicken and the paper manufactured at the mill on its bank showed signs of deterioration. An examination of the water was made and it was found to be polluted by salts of lead. Further investigation showed that a lead mine near Priddy on the Mendips, once worked by the Romans but long abandoned, had been reopened. Near it was a deep natural pit, into which, as a convenient receptacle, the refuse from the new workings had been thrown. That caused the mischief; for the pit also swallowed up the rain-water of the neighbourhood and this was polluted by the lead ore in percolating through the débris. This fact was so clearly established that an injunction was obtained prohibiting the practice.

Thus water can act on mineral substances both



mechanically and chemically; but instances of the former are much commoner than of the latter, while we shall find that it usually operates in both of these ways, sometimes the one, sometimes the other predominating.

As an example of the mechanical action we cannot have a better than the so-called earth-pillars (fig. 1). Striking specimens may be found in the Alps, though, as we shall presently see, they are not restricted to this region. Some of the finest groups occur on the Rittnerhorn, a mountain in the Italian Tyrol, one in a valley called the Katzenbach, about an hour and a half's walk from Botzen, and the other in the Finsterbach, about 500 feet higher and a couple of hours more distant. These valleys have been excavated in a porphyritic felstone and have subsequently been partly filled up with morainic material—a tough clay containing many fragments of rock, large and small. A mountain stream has cut a glen through this clay into the rock below and "on either side it is fringed by the earth-pillars. The upper part of the glen, on the first glance, seems to be filled with these rude obelisks, crowded like tombs in an overfull churchyard, but, on a closer inspection, a method is seen both in the order and in the shaping of the pillars. Now and then one stands alone...but the majority are connected, and many of them form ridges of clay, crested with pinnacles. Each is usually capped by

WITHDRAWN

a block of rock, like a turban: some, however, are bareheaded. On this block the existence of the earth-

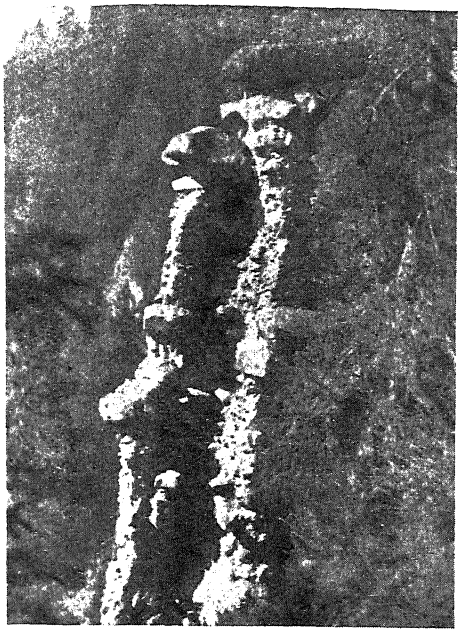


Fig. 1. Earth-pillars, near path from Viesch to Eggischhorn.

pillar depends; those which have lost their caps lose, not their heads only, but also their bodies. Here

and there the clay slope is furrowed by a rill, but for the most part the 'nullahs' between the ridges and the gaps between the pillars are perfectly dry in fine weather." A little study makes it clear "that rain has cut the gulleys and even furrowed the sides of the pillars; that the larger stones are essential to their formation; and that the clay becomes very hard on drying." At first it filled the glen; rills fed by rain worked at its surface, and as it quickly becomes soft when wet, they would soon plough a number of furrows into the mass; "one of these rills, in deepening its bed, would encounter a boulder, and be temporarily divided into two streams...Each of these, after the manner of currents, would wear away the bank of clay opposite to the stone, and would continue to work outwards even when its bed had been cut down below the level of the obstacle." The rills would be separated by ribs of clay, "but as these would be attacked by the rain, not only on both sides, but also from above, they would gradually disappear, and the capstones would remain exalted on pinnacles of stony clay." The rain, also, as the pillars increased in height, would do something, as it trickled down their sides, to reduce their thickness, but the capstone, like an umbrella, for a long time protects the pillar from serious harm. The latter, however, though slowly, becomes thinner; "the capstone less and less firmly supported, till at last it slips or is blown off. Then

the days of the pillar are numbered: from a pinnacle it is reduced to a hump, and at last is wholly washed away[1]." Similar pillars, though not generally so remarkable as these, may be seen in several other parts of the Alps, as, for instance, opposite to Stalden, near Useigne in the Eringerthal, near the path leading from Viesch to the Eggischhorn (fig. 1), and on the north side of the Brenner Pass. The late E. Whymper describes a remarkable group about three miles to the south of Briançon, in which, though large stones are frequent, capstones seem to be very rare[2]. In the Alps these pillars are not often more than thirty feet high, though a few of those in Dauphiné rise to sixty or seventy feet, but on the flanks of Mount Shasta in Northern California they may be found, according to the late Clarence King[3], of all heights up to 700 feet. In our own mountainous regions they are not common, but Sir A. Geikie[4] mentions some curious examples near Fochabers (Elginshire). These, however, are in a conglomerate of Old Red Sandstone age, and some remarkable instances cut from a sandstone of variable hardness have been described by American geologists. Here occasional lenticules, rather more durable than

[1] Quoted from *The Story of our Planet*, pp. 111–113, the account being written from notes of visits in 1872 and 1880.

[2] *Scrambles among the Alps* (1871), p. 431.

[3] *Mountaineering in the Sierra Nevada*, ch. xii.

[4] *Text-book of Geology* (1903), p. 462.

the rest, produce the effect of the larger boulders in the morainic material, crowning the pillar with a cap which sometimes is even flatter than a turban. In miniature, however, pillars may be found in many places both at home and abroad, wherever a bank of stiff clay mixed with flattish chips of stone is exposed to the action of rain. The first which caught my eye[1] were in the Val de Lys, above Luchon in the Pyrenees. Most of these did not reach two inches in height, though one giant was at least three inches.

In limestone districts many instances can be found, as we shall presently see, where the chemical action of rain-water far exceeds the mechanical, but for one in which the former alone operates we must look beneath the surface. When gravel overlies chalk, in eastern and southern England, a pit or cutting often displays the former filling a kind of shaft or pouch in the latter. These are called sand-pipes, and above one of them, the gravel which elsewhere is distinctly stratified has completely lost that structure, the position of the fragments sometimes even suggesting a downward movement. These pipes also occur where the chalk comes up to the surface of the ground, but then a little study of the neighbourhood shows that it was once overspread by gravel. No one now doubts that these sand-pipes, which once

[1] In 1876. Since then I have seen them in our own country and elsewhere.

greatly puzzled geologists, only admit of the following explanation. The gravel was deposited on an irregular surface of the chalk in which accidental depressions or cracks tended to concentrate the rain-water as it percolated downwards. As it contains some carbonic acid, it corrodes the chalk and deepens the depression, into which the gravel settles down. The process continues, and as will be easily understood, the pipe is prolonged. If the chalk contains layers of flint, these may for a time arrest the descent of the gravel, but the water makes its way through cracks and continues its work beneath them, till they break and slip down with the gravel. Thus the pipe may also contain flints unworn and obviously derived from higher positions. The chalk between Hitchin and Hatfield or between Croydon and Purley, as the railway cuttings show, is repeatedly pierced by these pipes. A yet stronger but less common proof of the solvent action of water can sometimes be found in a gravel containing many granules of chalk or fragments of shells. I remember to have seen a model, as it might be called, of a sand-pipe in a gravel pit at Barnwell, near Cambridge, and several of them in a large excavation in the shelly Red Crag near the south shore of the Deben estuary, a few miles from Woodbridge. The false-bedded Crag contained an abundance of shells, many of them in fragments. Some slight differences in the permeability of the

layers had produced a local concentration of the percolating water, which had dissolved the calcareous material, obliterated the bedded structure, and thus, as it were, given a sketch of a sand-pipe. Each was some three or four feet in height and perhaps from six to ten inches in breadth.

But more usually the mechanical and chemical effects are combined, as can be seen by tracing the action of water, especially when enough to form a stream, both on and below the surface of the ground. Rivers are the makers of valleys, rather than valleys of rivers. That was not generally admitted three-quarters of a century ago, but hardly anyone would now be found to dispute it. But we reserve the history of the change of opinion, which is both interesting and instructive, for a later chapter, and proceed to trace the processes at work in the making of a valley. In the upper part of Hampstead Heath an outlier of Bagshot sand rests on London clay. In this I saw a stage of valley-making on a small scale, when walking over it the day after an unusually heavy rainstorm. Some slight irregularities of the surface had given rise to a runlet of water which had rushed down a steep part of the north-western slope, where it had cut a steep-sided channel in the sand which soon became quite half a yard in depth and a foot or so wide. Here and there was a step, perhaps three or four inches high, in the bed of the channel, and

this was its history. The sand is not quite uniform in composition, for thin intermittent layers of it are harder than the rest, being cemented by iron oxide (limonite). The water, on encountering one of these, had its down-cutting action arrested, and acquired a plunging one at the outer edge. Thus a miniature waterfall was formed, below which the streamlet continued its course as before. Lower down, where the slope diminished, this tiny glen gradually broadened out and the sand formed a small alluvial fan. We had in fact here, as we shall presently see, a model of what occurs on a far grander scale in many parts of the world.

We may mention one or two other instances of Nature's models of special forms connected with valleys, because the circumstances under which they occur preclude any doubt as to their origin. At the back of Burntisland, a watering place on the north shore of the Firth of Forth, a fragment of an old volcano called the East Binn rises in a steep cliff. While scrambling along its base I came to a bowl-shaped hollow, a few yards in diameter, scooped out in the indurated volcanic ash, its sides furrowed by rills (then dry) which converged at the bottom and passed out through a V-shaped notch. In its leading features it was identical with the corries presently to be described in mountain regions. But I have also seen a model on a yet smaller scale. It was on

the same bank as those tiny earth-pillars already mentioned. The leading features, small as they were—for it was hardly half a yard across—were identical with those in the example at Burntisland. Now in these instances we cannot invoke any other agency than running water, and we see what characterizes its handwriting on the wall.

But these are not all. Early in May, 1902, the Soufrière volcano in the island of St Vincent, after ninety years of repose, broke into eruption[1] and ejected an enormous quantity of scoria and dust. To the south-west of the crater is a valley—that of the Wallibu River—descending from the mountain crest to the sea. This valley was filled in some parts to a depth of 60 to 80 feet with volcanic mud and other débris. But the old drainage lines were not altered, and the stream, swollen by the torrential rains, so frequent in this region, rushed down and soon cut deep, almost to its former level, into the incoherent débris. By the month of June the river course was bordered by cliffs, also furrowed by the runlets of rain, which had carved them into countless ridges, the flanks of which were yet more closely scarred by the rain which had fallen on them. This can be seen at a glance in some of the excellent

[1] It began, after some premonitory symptoms, on May 6, but a phase of violent paroxysms suddenly developed on the following day.

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photographs[1] taken by Dr Tempest Anderson when he, with Dr J. S. Flett, visited the island at the instance of the Royal Society (fig. 2). In the spring of 1907 he returned and found that, notwithstanding the

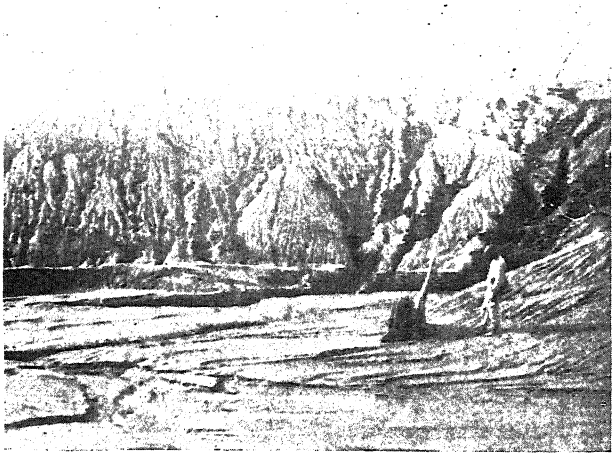


Fig. 2. Rain furrows, Wallibu Valley.

rich tropical vegetation which had spread its protective shield over parts of the new deposit, the former valleys had been deepened and still more widened;

[1] See *Phil. Trans.* A, vol. cc. Plates 28 Fig. 1, 29 Figs. 1 and 2, 33 Fig. 2, etc.

their steep flanks of débris being furrowed by rain-rakes, even more conspicuously than on the former occasion[1]. But the same lesson is taught by the cliffs of glacial drift on some parts of our eastern coast, by the Tertiary marls on the western flanks of the Apennines and by similar material in parts of the United States, such as the Bad Lands of Nebraska; numbers of little ravines running with almost parallel courses down the nearly precipitous cliffs, but now and again effecting a junction and cutting deeper into the slope. Can we then apply this explanation to the corries and cirques, the glens and gorges, which occur, sometimes on so grand a scale, in many mountainous regions? We can more conveniently discuss that question after considering some instances where the chemical often exceeds the mechanical action of water.

In many limestone districts (for in them the solvent action of the rain is much more conspicuous than elsewhere) the surface of the rock is often curiously pitted, grooved, scarred and barren. These features are common in the Carboniferous limestone of the Dale-land in Western Yorkshire, in many parts of the Alps, especially in the Karst region of Carniola, and in the noted Steinerne Meer in the Salzburg Alps. The last is a plateau about five miles in length and fully two miles in breadth, which is rather more than 6000 feet above sea-level. A more dreary

[1] See *Phil. Trans.* A, vol. CCVIII. Plates 9–12.

spot could not easily be imagined. Here and there, but very seldom, is a ragged *latschen*[1] or other blasted pine, ill-grown, twisted by the wind, perhaps dead, but the region, except for a rare and faint streak of green or a few stunted and starveling alpine plants, is a wilderness of rock, weathered into myriads of holes of the strangest form, ramifying into shallow gulleys and often ending in pipes or narrow shafts which pierce vertically into the mass. Neither rills, nor streams, are visible; the melting snow and the summer rain are quickly swallowed by these innumerable mouths. Similar instances of water channeling can be found in the neighbourhood of the Gemmi Pass and other limestone districts of the Swiss or Savoy Alps, but nowhere are they better or more easy of access than in the lake region to the south of Ischl. But some parts of England, especially in Western Yorkshire, afford a striking object-lesson of the solvent power of rain. Here and there, in a hilly limestone district, large blocks of hard grits have been dropped, during the glacial epoch. They must have been deposited on its surface: they now stand on pedestals from about twelve to twenty-four inches above the present one; these indicate the thickness of the layer which has been removed, and that by subaerial action alone, during the interval, whatever

[1] A kind of dwarf-pine (*P. pumilio*).

may have been its length, between the disappearance of the ice and the present day (fig. 3).

One more instance may be given of the power of running water, in this case largely supplied by melting



Fig. 3. Erratic Block, on pedestal. Norber.

snow. Professor Garwood has described[1] how, in Spitzbergen, a level plateau, of rather incoherent materials, was capped with snow and terminated in a rather

[1] *Geographical Journal*, vol. xxxvi. (1910), p. 310. Pl. I fig. 1.

steep slope above a lowland by the sea. The snow had a protective effect on the plateau, but in the summer season it fed numbers of rivulets, differing little in size, which made their way down the slope, and caused it to look as if it had been furrowed by a gigantic rake, for they generally followed an independent course from top to bottom.

We may now trace the underground course of the water swallowed up on these surfaces of limestone. In sundry districts, including those already mentioned, a stream contrives to form and run for some distance before it is engulfed. The 'pots' or 'swallow holes' of Western Yorkshire have long attracted notice, and there is no more striking or instructive instance than Gaping Ghyll, which is at a height of nearly 1350 feet above sea-level on the western flank of Ingleborough. Here, where the Carboniferous Limestone is exposed at the surface, it is carved into basins, channels and pipelets, but it is sometimes covered by a few feet of drift. In one of these areas a little stream—the Fell Beck—has cut down to the limestone. On either side the banks slope for some yards down to the water. But looking along its course we see that they curve round so that the valley ends, though in the wrong direction. A few steps more and we have the explanation; the water plunges into an open shaft about six yards wide and five yards across. This shaft was descended in

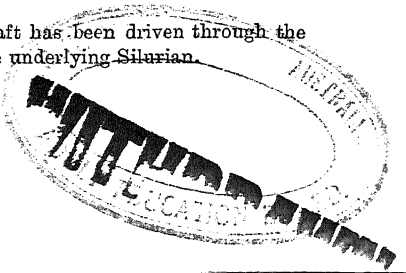


August, 1895 by Mr E. A. Martel[1] with the aid of a rope ladder at the end of a stout cord. At the top is a small side opening which leads to an irregular shaft ultimately joining the main one. Professor Hughes had already sounded this, and found the depth to be 330 feet, a measurement confirmed by Mr Martel. The falling water afforded him an abundant and increasingly vigorous shower-bath, which, however, did not cause more than inconvenience. On approaching the bottom the explorer found himself suspended in a large open space, and on reaching the ground found that the shaft ended in a 'vast hall, 500 feet long, 80 to 100 feet high, 66 to 116 broad.' It was blocked at either end by fallen rock, the water escaping through the eastern mass of débris[2].

Some years before Mr Martel succeeded in exploring Gaping Ghyll it had been discovered what became of the engulfed water. In the rocky flank of a valley, near the village of Clapham, rather more than a mile away in a straight line, are the noted Ingleborough caves. These evidently have been cut by a stream, which emerges a short distance farther up the valley, after working its way through an exceptionally hard bed of limestone, the presence of

[1] E. A. Martel, *Alpine Journal*, XVIII. p. 120, and *Irlande et les Cavernes Anglaises* (1879), ch. xxiv.

[2] According to Mr Martel the shaft has been driven through the Carboniferous Limestone down to the underlying Silurian.



which no doubt led to the formation of the caves. The connexion with Gaping Ghyll was proved, not only by throwing chaff and colouring matter into the water which plunges into it, but also by the help of nature. Several years ago a 'cloud burst' on Ingleborough changed the stream into a torrent; in due course the water at the outlet in the valley increased in volume till it flooded the upper cave, resuming for a time its ancient channel[1]. In not a few caves water springs from openings in their walls can be followed for a time, and then passes out of sight on an independent journey, or a dry cave joins another one down which a river is flowing.

Caves and swallow holes abound in the Carboniferous Limestone districts of England, Ireland, Belgium and the United States, some of them, especially in the last country, far exceeding any known in Great Britain. The limestones also of Secondary age, in many parts of the Alps, and still more in the Causses of France (the plateau region drained by the Tarn, Lot and Dordogne) afford numerous caves and subterranean watercourses. In every mountainous region where water is swallowed up on the higher ground it may break out on the face of a cliff or at its base in the bed of a valley below. The

[1] See W. Boyd Dawkins, *Cave Hunting*, ch. ii. for other instances in England. The distance between the farthest point reached in the caves and Gaping Ghyll is about 4000 feet, the fall being about 130 feet.

annexed diagram (fig. 4) shows how local conditions have modified the form of the culvert, which has now become dry because the stream has sought another path; but instances of streams issuing from the rocks in fairly full vigour are too many to enumerate. The Sorgues at Vaucluse near Avignon, the cascades

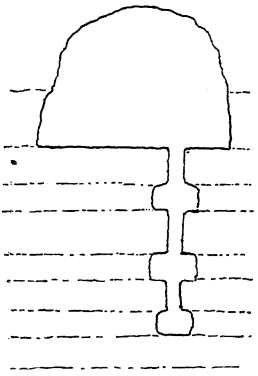


Fig. 4. In face of cliff, near Untersberg, Salzkammergut.

about the Drei Brunnen at Trafoi, in the Tyrol, the Sieben Brunnen of Lenk in the Western Oberland, the Orbe and the Loue in the Jura[1], are all instances of the emergence of water, which has been elsewhere swallowed up, and perhaps joined by other streams

[1] E. Reclus, *The Earth*, ch. xliii. E. A. Martel, *Les Abîmes*, p. 437. G. F. Browne, *Ice Caves*, pp. 59, 122.

during a subterranean journey. The region of the Karst, which has already been mentioned, is pierced by funnels and riddled with caves. The most remarkable instances of the latter are those near Adelsberg[1]. To the north of the town the river Poik enters a portal in a limestone crag and can be followed for more than a thousand yards, being joined near the entrance by the famous caves which are now dry beds of that river or of tributary streams. The Poik, after a subterranean course of about twelve miles, during which it can be approached in one place down an opening from above, emerges under another name, the Planina, but their identity is beyond reasonable doubt. About a dozen miles to the south-east of Adelsberg limestone cliffs surround an extensive and generally level basin. The floor of this is pierced by funnel-shaped holes about 400 in number. These, for the most part, are dry, but water rises up into them after heavy rain, and sometimes actually overflows in such abundance as to change the plain for a time into a lake, the area of which has been known occasionally to be nearly 25,000 acres. There must be a number of subterranean channels in the limestone rock, communicating one with another and forming a regular drainage system, which becomes so gorged with water as to be unable to carry away all of it; thus the rest 'backs

[1] E. Reclus, *The Earth*, pp. 295–299.

up' the shafts and overflows the surface which they generally keep in a very dry state.

In all these swallow holes and caves the erosive action of the water is largely, and in some cases mainly, chemical, but we must not forget that wherever it falls from a height or is running rapidly, it exerts a mechanical force, and this, in such cases as Gaping Ghyll or similar shafts, must increase with the depth till at last it may exceed the other one. The fact, however, that natural shafts, swallow holes, and caves are very rare, if not wanting, in all but limestone regions, proves that chemical action is the more essential condition for their occurrence.

One effect, on the whole mechanical, of water when percolating beneath the surface must not be forgotten, because it is sometimes locally important. After continuous wet weather the ground becomes saturated to a considerable depth, the coherence of the materials is diminished and on sloping surfaces landslips may occur. This often happens on the banks of railway cuttings in the London clay, though they are protected by herbage and sometimes strengthened with burnt material. When the mass has been 'lubricated' to a depth of two or three feet, the turf above begins to bulge; then it cracks, and finally slips down. After heavy rains these slides have sometimes temporarily blocked the lines. The same thing happens on a larger scale when a permeable

stratum ending in a cliff rests upon an impervious one which slopes outwards, as in the case of the famous landslip which occurred, after a very wet season, on Dec. 24, 1839 between Lyme Regis and Axmouth. Here a mass of chalk ending in a cliff above the sea passes down into a less coherent calcareous greensand, beneath which is a shaly clay of Liassic age—all sloping seawards. The last-named bed arrested the downward passage of the water, which saturated and loosened the greensand until a broad strip of the overlying chalk, more than a hundred feet in thickness and three-quarters of a mile in length, slid down seawards, breaking up into rudely prismatic blocks.

In mountain regions, where the rocks are often tilted at high angles and the valleys cut deep into the successive strata, these landslips are on a greater scale and far more terrible. Such, for instance, was the historic fall of the Rossberg in Switzerland. This is a mountain rising some 3500 feet above the valley between it and the well-known Rigi. Permeable rocks overlie, with an outward slope, comparatively impervious strata, and here, after an exceptionally rainy season, a great mass of conglomerate, some three miles long, 350 yards broad and about 100 feet thick, slid down to the valley on Sept. 2, 1806, breaking up into fragments as it went, and destroying about 94 acres of fertile land and three villages with part of a fourth,

thus bringing death and burial to 484 persons. Not a few similar cases, where water has added catastrophic to its ordinary results, have occurred in the Alps and other mountain chains.

CHAPTER II

THE MAKING OF VALLEYS

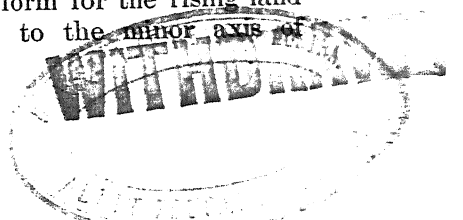
We have endeavoured to prove in the preceding chapter that water in its liquid form is a powerful agent in earth sculpture. It is aided no doubt by heat and cold and the wind, it may act in the form of ice or of the sea, but each of these produces its own results, and the denuding effects of rain and rivers can be appreciated by tracing the history of valleys. These also can be found in miniature and the processes of making be watched.

When the water is draining off from a gently shelving sandy-shore, just exposed by the receding tide, we find the level of the surface quickly broken by a number of channels. They begin sometimes almost imperceptibly, but quickly develop into tiny watercourses with rather steep walls and flat beds. The walls are steep, because the material is homogeneous and fairly coherent; they are rather low and the bed is flat

rather than angular in section, because the coherence soon reaches its limit. At first these streamlets are fairly numerous, but they tend to unite on their downward course, because if any one of them be diverted by some chance obstacle, it will be directed from a straight course towards one of its neighbours and in some cases it may take an oblique path from the beginning. Thus a map of these watercourses often resembles a drawing of a leafless twig of a beech tree or of willow roots when spread out in water. But as the slope steepens, the number of these tributaries diminishes, their length increases and when we pass from this gently shelving floor to a bank of steep stony débris, we find that the many twigs pass into one strong stem with few and insignificant off-shoots. Thus a river system, to give a very rough comparison, may present a variety of types from the growth of a beech to that of a Lombardy poplar, the latter one being common in any mountain region. We mentioned their occurrence on a small scale in close furrowed slopes of mud and débris, and they are exhibited on a larger one by almost any steep slope in such a region as the Alps. Sometimes, as will presently be described, their beginning is a tiny corrie, but more often a gradually enlarging furrow, at first barely perceptible, makes its appearance on the slope, without being joined by any tributary large enough to be noticed from a distance. The

section of the furrow, so long as it is cut through débris, is V-like, because its flanks are not sufficiently coherent to remain in an upright position, but if it reach the underlying solid rock, the form of the channel will be changed, the walls become steeper and the groove more of a gash. To these and other modifications in form we shall return, for the moment it is enough to notice that in all cases the brooks gradually unite to form a river, and the rivers may combine in a great trunk stream.

Suppose then land is beginning to rise from beneath the sea, as a low dome. Assume this, for the moment, to be circular in plan. No sooner is it exposed to the sky, than the rain will fall upon it and will begin the downward transport of its materials. These possibly may be removed so uniformly that the rounded outline will be retained and the dome be gradually lowered till at last it is hardly more prominent than a shoal when bared by a falling tide. But such uniformity would be exceptional. Usually the sculpturing process will begin at once, and little river systems be initiated, as above described. These will radiate outwards, to the different points of the compass, and as elevation continues, will obviously be less and less likely to unite. Such an area would exhibit a number of rivers about equal in magnitude. But a much more probable form for the rising land is a very elongated ellipse, to the minor axis of



which the majority of the larger trunk streams would be parallel. Another factor will almost certainly enhance this inequality of development. Before the crest of the dome emerges from the sea it will be attacked by the waves, which will plane away its surface, and if it is formed of stratified rock, the area finally uplifted will consist of a series of elliptical shells, the materials of which differ in their powers of resistance. Suppose them to be alternately hard and soft. In the former the V-like section will be preserved, but the latter yields more easily and another modification appears. The rain, which has fallen on this portion, will soon be checked in its downward course by the outer band of hard rock, and will wander over the softer material, making some sort of a channel in this until at last it meets with one of the radial grooves. This develops a second system of valleys, making a high angle with the others, and bounded on either side by the outcropping harder rock.

Thus the valley courses in an elevation of this nature form two groups, the one following the dip, the other the strike of the beds, and named from that dip valleys and strike valleys. Even crystalline rocks not unusually show a system of divisional planes, more or less resembling stratification, with a jointing perpendicular to them, so that the terms dip valleys and strike valleys may also be extended to them, but

we may avoid any difficulty of this kind by calling them, where speaking of them inclusively, transverse and longitudinal valleys[1]. Complications will be introduced by inequality in the uplift, by its occurring, with apparent independence, in different places, and by actual movements in the opposite direction, but to these we may return; for the present it suffices to say that this method of river formation is the key to the physical structure of any area of the earth's surface, be it large or small.

The beginning of a valley assumes more than one form. Sometimes it starts from a rather bowl-shaped head; sometimes a very faint notch gradually becomes perceptible on a slope, broadening and deepening on its downward course. The former is due to the concurrence of a number of streamlets, of which none, when the hollow is a small one, is strong enough to mark its path by a furrow and which unite, owing to some favourable circumstance in the original configuration of the ground, almost at the same point, and then have sufficient power to cut a notch. The exact outline—the slope of their sides—in both the one and the other, depends on several conditions,

[1] Some authors of late have preferred to call them 'consequent' and 'subsequent' valleys, but the multiplication of terminology seems to me an evil which in this case has not the compensation of greater simplicity and explicitness. 'Transverse' and 'longitudinal' were the terms used by J. B. Jukes to whom we are indebted for a most important paper on valley-making. See page 132.

but notably on the nature of the rocks which are being carved. If these are fairly hard and homogeneous, the walls will be steep ; if soft, they will be gentle, if variable they may be in steps. Among our English chalk downs the heads of the valleys very often are more or less bowl-shaped, and here the slopes of their sides become rather steeper, but sometimes they seem to die away almost imperceptibly among the hills without any attempt at a notch. This is because chalk is soft, uniform in texture (flints of course excepted) and readily yields to the corrosive action of the atmosphere. In our more mountainous districts both types of valleys occur, but perhaps that starting with a faint notch is the commoner, and the outlines throughout are of a bolder type.

These bowl-like hollows often become larger as the hills increase in size and their walls steepen in the more durable rocks. They are then called corries and cirques—the latter term being reserved for those which have the steeper walls—and are due to the action of rather numerous convergent streams in rocks which, though strong enough to maintain fairly vertical faces, yield rather readily to denuding agencies. Some writers have attempted to draw a distinction between small cirques, which they call alcoves, and large cirques, and to associate the names with a difference in origin. This distinction appears to me, after an experience of more than forty years, to have

no valid foundation. As with the corries, so with the cirques, you may pass from small to large, from the pigmy to the giant. I have seen a model cirque as well as a model corrie. It was in a large pit in the Bunter pebble-bed, worked near the Cannock and Rugeley railway (Staffordshire). Here, after an unusually heavy rainstorm, a semicircular recess had been cut in one place downwards from the surface. Its walls were vertical; perhaps about four feet high (the diameter being rather less), and its bed like half a saucer. Here the streamlets had not made any perceptible furrows on the side, probably because the pebbles compelled each one to follow a rather zigzag course; but in the larger cirques the furrows are often plain enough.

The following quotation[1] describes two which may be seen from the rugged pastures of the Blacken Alp (5833 feet) on the way from Engelberg to the Surenen Pass. They are cut out of the highest part of the Uri Rothstock *massif*, and separated by a spur named Rothschutz on the Federal Map and are very similar in appearance, though the eastern one, on the whole, is the finer of the two (fig. 5). "Its other extremity is the Blackenstock (9587 feet) and from this summit to the Rothschutz (9278 feet) runs a line of crags not much inferior in height; the chord joining their two ends is about 2800 yards long, and the sagitta of the arc,

[1] The author, *Quart. Journ. Geol. Soc.* vol. XXVII. (1871), p. 314.

about 650 yards: but the spurs projecting from the two extremities give a more semicircular appearance to the cirque than these measurements would suggest. Above the usual taluses of débris rises a high band of cliffs of a hard yellowish limestone, which supports

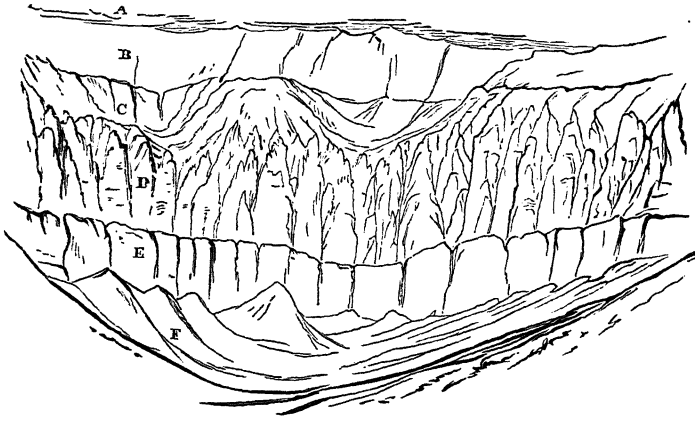


Fig. 5. Cirque in Rothstock. A. Clouds concealing peaks. B. Limestone cliffs. C. Shaly slope with small corries and snowbeds. D. Shaly cliffs furrowed by streamlets. E. Limestone cliffs slightly grooved by these. F. Floor of cirque with talus heaps on side.

a still loftier belt of a reddish rock, doubtless a rather sandy and coarse calcareous shale: over this is a sort of terrace-shelf or slope, hollowed out into small combes [corries]; and then rises another barrier of limestone cliffs forming the lip of the cup-shaped

hollow. Clouds prevented me from seeing the sky line in more than one place, but it is nowhere more than a few hundred feet below the peaks named above. For the same reason, I cannot attempt to give any accurate estimate of the height of the cliffs; but the two lower stages appeared to me together not less than 500 feet. The strata lay tolerably horizontal, only curving upwards somewhat in the western part of the western cirque. The most remarkable thing about the cliffs was the belt of reddish shaly rock, which was furrowed by a vast number of little gorges —which were often only a few yards apart and occasionally united—so that this part of the cliff really looked like a badly ploughed field set up on end. Down these gorges, many of them dry in August, little rills descend from the snow on the ledges and in the combes above, which have generally made some trace, corresponding with their size, on the harder limestone below—sometimes a mere stain, sometimes a well-marked groove."

Still larger cirques may be seen in other parts of the limestone Alps, such as Am Ende der Welt at the head of a glen to the north of Engelberg, the Fer-à-cheval near Sixt and the magnificent Creux de Champ in the Diablerets near Ormont Dessus. Somewhat smaller are the Croda Malcora cirque[1] in the Sorapis

[1] *Id.* p. 313. I went up into it in 1872 and was satisfied that though inferior to Gavarnie it was a true cirque.

above Cortina d'Ampezzo in the Dolomites, and that of the Creux du Van in the Jura. The Pyrenees also afford several examples, the best known of which is the famous Cirque de Gavarnie. But among limestone mountains, they may be found of all sizes from such as these downwards. The annexed engraving (fig. 6) gives a rough sketch of a small cirque, high up in the limestone cliffs, on the left bank of the Aa valley, a short distance from Engelberg. It is an exceptionally good illustration of the genesis of a cirque, for here six or seven small streams issue from the rock and have worked out a hollow, only a few dozen yards wide, yet of the true cirque type. It would be easy to quote other cases, where small cirques or corries are developed on the face of great walls of limestone rock, in a position where it is impossible, so far as I can see, to invoke any other agency than that of small streamlets, fed by springs or by little gatherings of snow on ledges above.

Among crystalline non-calcareous rocks, cirques are far less common. Here they generally take the shape of corries; that is, their walls are not so often vertical, and their outlines a little less regular, since the materials generally are not so favourable to the production of such numerous streams or of vertical precipices. Still cases may be found, as for instance, high up on the eastern side of the Grand Combin, where the névé basin of a glacier is enclosed by a

sweep of cliffs, which, did the ice melt away, might well be claimed for a cirque. The situation of a cirque or a corrie, it may be well to remark, is not always at the head of a valley. The Fer-à-cheval,

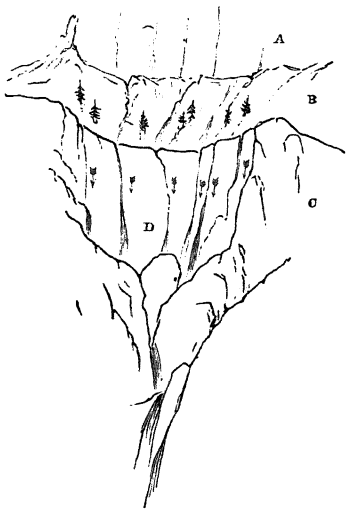


Fig. 6. Small cirque near Engelberg. A. Limestone cliffs. B. Shaly bank with some trees etc. out of which the streams break. C. Limestone cliff. D. Cirque. ↓ Cascades.

for instance, and the two cirques under the Uri Rothstock are both at the side of a well-marked valley so that it is extremely difficult to understand how glacier ice could exercise that 'sapping' and

'plucking' effect which has often been invoked of late years, but which I believe to be largely imaginary.

Cirques, in short, require for their development, unless I wrongly interpret the evidence, the co-existence of the following conditions: (1) several small streams, which are fairly constant and have a tendency, from the shape of the ground, to be confluent, (2) strata, moderately horizontal, over which these streams fall, and which by their constitution yield considerably to the other forms of meteoric denudation, (3) these strata must nevertheless allow of the formation of cliffs, and thus perhaps the most favourable structure is thick beds of limestone with occasional alternating bands of softer rock.

Gorges are perhaps the most impressive forms produced by strong and rapid streams acting on durable and homogeneous rocks. Thus they are frequent in mountain regions; becoming smaller among hills, and vanishing as these subside into plains. In the Alps they are common, especially where the velocity of a stream is suddenly increased by descending a step in the bed of a valley. Here, for instance, the floor of a lateral glen at its junction with a main valley is often much higher, perhaps some hundreds of feet, than the latter, so that a steep almost precipitous descent leads from the one to the other. Opinions differ as to the exact explanation of these hanging valleys, as they are called, but, whether

the larger river has deepened its channel more rapidly than the smaller one, or glaciers in the two valleys have produced the same effect, a gorge, like a great notch, is almost always found in the lip of the above named rocky step. They occur alike in the limestone and the crystalline districts. Among the former are the gorges of the Rosenlaui and the two Grindelwald Glaciers. That of the Unter Glacier, a magnificent example, was hid beneath the ice half a century ago, but it was exposed by the rapid shrinkage of the glaciers which began soon after 1860, and it has since then been made accessible. Its head is masked by ice which still covers the upper part of the last step in the bed of the mountain valley, but fine views of the rest can be obtained from above and from a gallery constructed by the side of the torrent. The gorge is a few yards wide, its limestone walls rising almost vertically, and retaining in many places the indications of torrent action far above its present level, in some cases to the top: such as scooped-out hollows of all sorts and even pot-holes, often partly cut away as the channel was lowered, till at last the gorge is choked by ice from the glacier above. But similar gorges, which no doubt were begun, if not sometimes mainly formed, in the same way, occur in many parts of the Alps. Such are those at the entrance of the Eringerthal and of the Einfischthal, that of the Trient at Vernayaz (fig. 7) and of the Tamina at Pfäfers:

those on each arm of the Visp near Stalden, the one cut by the torrent from the hanging valley of Saas Fee, and a host of others, small and large, which it is needless to enumerate. These, however, are made by

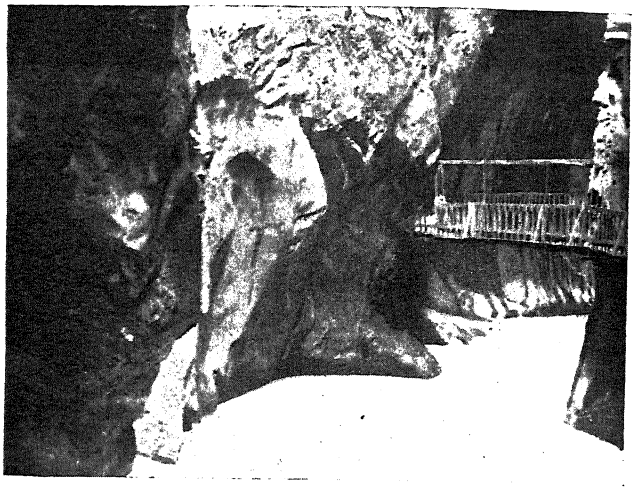


Fig. 7. Gorge of the Trient, Vernayaz.

torrents largely fed by glaciers, the grit and mud from which must greatly augment the cutting power of the water, and when they occur in such districts as Wales, Lakeland, or the Scotch Highlands, they may be regarded as being, to a great extent, relics of the

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Ice Age. In fact, though gorges may be found in regions where even permanent snowbeds are not likely to have existed, they are rare in occurrence and small in size.

One kind of gorge demands a brief notice, though the precise explanation of it has been much disputed. On this question, however, we need not dwell, because it does not affect the main point, that the gorge was cut by a torrent. This kind, however, differs from the others in traversing a barrier which crosses a valley. That of the Kirchet is the most noted instance. Here the bed of the Aar valley, between Imhof and the level plain extending by Meiringen from the lake of Brienz, is crossed by a limestone barrier over 300 feet in height, through which the river has cut a path, seldom more than a few yards in width, and at the lower end so narrow in one or two places that a man may almost touch the walls with outspread hands. Here also, the lower parts are waterworn in the usual way, and no doubt the marks once extended up to the top. A century ago this gorge would probably have been regarded as a rift produced by some convulsion in the earth's crust, but a closer study manifests the improbability of that explanation. The longer and lower part of the gorge is now made accessible by a slight gallery of wood. Visitors, who have reached the end of this, can vary the expedition by ascending a steep ravine which

leads to the upper part of the Kirchet barrier. (the sides of this, also, he will recognise the signs water action. Down it a tributary stream, fed by t glacier which once passed over the Kirchet, but l long melted away, must once have plunged. It l no resemblance to a crack, but is identical w dozens of lateral gullies on the flanks of ordin ravines. If then it has been the work of a stre we need not hesitate to ascribe the other one to same agent.

Gorges of this kind are not very numerous in Alps, though, as we shall presently see, narrower broader parts often alternate in their valleys, there is a fine example, that of Sottaguda, n Caprile in the Dolomites. The Rhone also at Maurice cuts through a limestone barrier which r across the valley, and it is noteworthy that both h and at the Kirchet this barrier is not severed q at its lowest point. On that fact, however, which more than one explanation has been propo we need not linger, since, whatever may have b the directing influence, we cannot doubt that a tor has been the agent which has severed the barrier. fact, as we wander up and down the valleys in Higher Alps or Pyrenees—we mention these bec the 'writing on the wall' is in bolder characters t in our own country—we find that where a str descends a step, whether in a lateral valley or at

junction of one of these with a main valley, it makes its mark upon the edge. This, if the stream be small, and especially if it be clear, may be hardly perceptible, but as its volume and its turbidity increase, or in other words as it is more largely supplied from glaciers, its channel becomes a groove and the groove deepens and extends backwards till it becomes a gorge. The torrent, which carries down to the Visp at Saas the drainage from the glaciers in a gigantic corrie—the peaks of which extend from the Mittaghorn to the Nadelhorn—flows with little disturbance over the comparatively open floor, but, immediately after leaving Saas Fee, it plunges down a ravine in the rocky step at the mouth of the hanging valley. That village and Saas Grund in the main Visp valley are separated by a rocky wall about 800 feet in height, into which the torrent has sawn a channel. The bed of this slopes steeply, for the torrent emerges on a level with the main river.

The depth of one of these gorges at the end of a hanging valley depends on the erosive power of the torrent. Here, where it is large and its waters turbid with débris from the glaciers, the gash is on a grand scale, like several which have been already mentioned, but we can demonstrate the importance of both conditions without quitting this part of the Vispthal. On its opposite side, within a distance of about four miles, three torrents emerge from hanging

valleys, all terminating in a well-marked rocky step. In the southernmost, and the middle one—the valleys leading to the Antrona and the Zwischbergen passes —the glaciers are unimportant and in each the lip of the step is but slightly notched, but in the northernmost, where the glaciers are rather larger, the notch is a little more deeply cut though it is in no way comparable with the great gorge on the other side of the Vispthal.

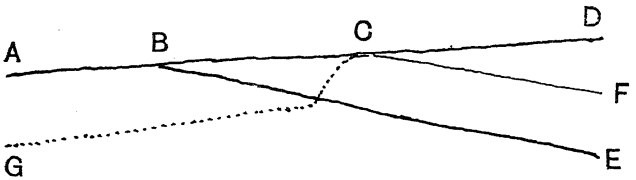


Fig. 8. Cutting a step (the dotted line).

Waterfalls are also instances of the cutting power of a stream. Illustrations on a small scale are frequent in a hilly or mountainous region. As a simple one suppose a bed of hard rock (*BECF* in the diagram fig. 8) to crop out on a smooth surface *ABCD*, shelving slightly towards *A*, between two softer beds *D* and *G*, and a stream to begin moving along the line *DCBA* in the direction of the lettering. The bed *BECF* would be worn away more slowly than those above and below it. In the upper of them the stream could

not appreciably deepen its bed, but as soon as it encountered the softer rock beyond *B* it would begin to cut down into it. This would set up a slight plunging motion in the water, and initiate a step protected by the outcropping edge of the harder rock. The result would be a slight increase in the velocity of the stream above the step and a corresponding one in its erosive powers. The whole thickness of the harder bed would be exposed together with a greater amount of softer rock beneath it. The backwash of the water would begin to work upon the latter and undermine the ledge: pieces of that would fall, and the cascade recede upstream (fig. 9). Good illustrations of this can often be found on mountain slopes at the outcrop of alternating banks of limestone and shale, and it may be worth noting that in cases where that outcrop makes an oblique angle with the course of the stream it not only comes down in a series of little steps (the height and breadth of each depending, of course, on the thickness of the beds), but also works away to one side—that towards which they are sloping—so that the section of the furrow instead of being a regular V has the steeper arm on that side. Many waterfalls have been formed by that undermining process, and even Niagara has been caused by a thick nearly horizontal bed of limestone (about the same age as the Wenlock limestone in Britain) which overlies one of more perishable

materials. Here, everything is on a grand scale, but we may trace the process through any number of graduated examples down to the rivulet as it tumbles over a tiny cliff but a few inches in height.

Since 1678, when the Falls of Niagara were seen

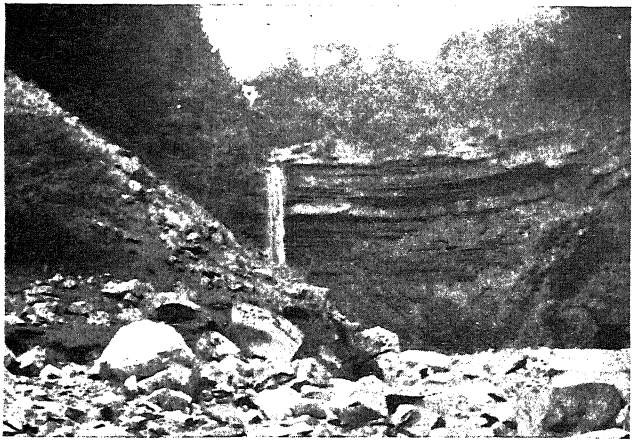


Fig. 9. Hardraw Scar, Yoredale.

for the first time by a European, Father Hennepin, they have receded for some distance up stream and have changed considerably in form. The extent of the latter is difficult to estimate for his rude picture so greatly exaggerates their height that a comparison

of the details is difficult, but there are no signs either of the great 'horseshoe' on the Canadian side or of the deep notch by which of late years its outline has been injured. For nearly a century after that date Niagara was seldom visited. But now the Falls have been carefully studied for fully seventy years; and the results published by observers both in Canada and in the United States. Dr J. W. Spencer has given an elaborate summary of the results of work done by himself and others in a volume entitled *The History and Geology of the Falls of Niagara*[1]. When he wrote the height of the Canadian Fall, which is slightly the lower, was 158 feet, and the width of the gorge immediately below was 1200 feet. Between 1842 and 1905 the average rate of recession had been 4·2 feet a year, but the amount was decreasing, and for the last fifteen of those years had been reduced to 2·2 feet though in the preceding fifteen it had been 4·4 feet. This change is probably due to a marked reduction in the volume of water which passes over the Falls, so much having been abstracted of late years to work machinery, especially for conversion of the water power into electricity. By this abstraction, as Dr Spencer states, the beauty of the Falls has been impaired. The depth of the water in the neighbourhood of Goat Island has already been reduced by

[1] Published by the Geological Survey of [illegible] 1907.

WITHDRAWN

over a foot with the result of laying bare rock in the shallower part, and he anticipated that at the present increasing rate of diversion the American Falls would be reduced from a sheet of a thousand feet in width, to a few narrow streams coursing down the deeper channels, and the depth of water on the Canadian side lowered by two or three feet[1]. "Niagara Falls reached their supreme magnificence by 1900 when the perimeter of the Canadian Falls was 2950 feet and the American 1000 feet. The whole is now reduced by encroachment to about 3500 feet. With the use of the full franchises the entire width of the falls will be reduced to 1500 feet and then they will be wholly in Canadian territory, except small streams coursing down the ancient river bed over the Goat Island shelf and the present route of the American channel and falls." Thus, with the twentieth century, Niagara has been appropriated for the production of wealth, but has ceased to have value as a geological time-piece.

More than one estimate has been made of the number of years which have elapsed since the Falls began to carve a channel in the limestone plateau, beginning at the edge of the escarpment at Queenstown about seven miles below their present position. At first, according to Dr Spencer, their height was only about 35 feet and their channel very much

[1] *Loc. cit.* p. 267.

er. Now the depth of their bed, as near as it measured to the foot of the cascade, is from 100 feet. The history, as he relates it, is a complex one, and the result has been much on in the time-estimates, as the several stages process have been recognised. If the recession en uniform and at the rate of four feet a year, ginning of the Falls would have been 9000 ago. Bakewell in 1829 had allowed 12,000 Lyell in 1841, by taking a slower rate of on, gave it as 35,000, but greatly reduced this after obtaining more precise estimates of the change. Dr G. K. Gilbert in 1886 put it so 7000 years, by using for the calculation the um amount of recession, the mean rate of would give 9000 years. Dr Spencer, making ace for a much slower rate in the earlier stage ession, argues in favour of a considerably figure, a total of 39,000 years, from which, if vering of the Erie basin—an early stage—be apid than he had estimated, 3500 years must ucted. Thus Lyell's original estimate, which tle more than a conjecture, corresponds very with the results of an elaborate investigation. ld, however, be premature to say that the versy is at an end, but we may venture to that the age of the Falls as a whole is not than the figures just quoted. As this work

has been carried out in post-glacial times, it gives some help in any effort to approximate the date at which the Ice Age came to an end.

The form of the cross-section of a valley next calls for attention. If the walls on both sides of a gorge are practically vertical, it must be cut in rock which is not only hard but also uniform in power of resistance. If, however, that consists of horizontal beds of harder and softer material, the latter yield more readily to meteoric agencies of denudation; thus weakening the foundation of the former, and causing pieces of them to fall. Then, instead of a vertical wall we have a series of crags alternating with slopes, a structure which is usual in the valleys of mountain districts carved out of suitable sedimentary rocks, and may also be seen, though generally less conspicuously, even among those which are crystalline, for they also, as already said, not seldom have a rather similar divisional structure. If the outcrop of inclined beds be generally parallel with the direction of the stream, the sides of the valley will slope at different angles, for, whether the rock be sedimentary or crystalline, it is usually affected by a system of joints, more or less perpendicular to the bedding or its equivalent, which divide it into blocks. The equilibrium of those on the one side is comparatively stable for, if slightly disturbed, they are brought back by gravitation to their former

position, but on the other it is the reverse, so they are readily displaced (fig. 10).

Hitherto the channel of the stream has been assumed to be a straight line. In that case its rate of flow is greatest in the middle, and is the same on either side, but if the channel be curved the velocity is greater near the concave than the convex bank.

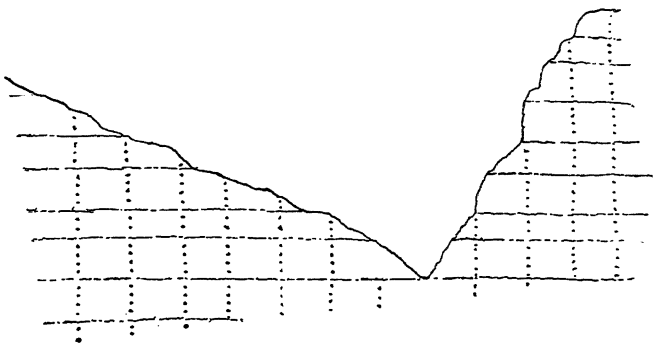


Fig. 10. Effect of bedding and joints (dotted lines) on form of valley.

The former will therefore be worn away more rapidly than the latter, on which also the bed will 'shallow' more slowly. Thus the process of erosion keeps the concave bank the steeper of the two, and the whole valley not seldom presents that form. Again as the slope of a valley-bed diminishes, which, as will be seen, it usually does, the velocity of the stream is diminished

hill, against which it presses as it approaches the little town[1].

The valley of the Rhine between Bingen and Bonn affords a similar section (figs. 12, 13), except that the flat parts, unused by the river, are perhaps more frequent and certainly on a larger scale. The Moselle for many miles above Coblentz has a general resemblance to the other river, but in this valley the tracts of flat land by the water's edge are less conspicuous. But



Fig. 12. Diagram of Rhine valley near Godesberg.

it is worth noting that in all these cases the valleys of tributary streams which, as descending from the upland have a more rapid fall, are generally V-shaped. In fact, the trough section, the height and slope of the sides and the breadth of the base, depending on circumstances, are characteristic of a stream sufficiently strong and full to overcome the obstacles of its environment, but not enough to make it act as a saw. Though nothing more than a brooklet, perhaps not

[1] A map of the former district is given in *Les Roches dites plutoniennes de la Belgique et de l'Ardenne Française* (Poussin and Renard), Pl. vii. and in *The Earth* (Reclus), p. 357.

even a drop of water may now be flowing along a valley which presents these outlines, they show that this was not always so, and that we need not hesitate to recognise it as a memorial of an old and fairly powerful drainage system.

In this connexion may be mentioned a singular, apparently anomalous, feature in some hilly limestone districts, namely the occurrence of valleys which are either always, or at least usually, quite waterless. These prove on examination to be, not deserted fragments of some earlier valley-system, but complete



Fig. 13. Section of Rhine valley.

in themselves, exactly like those elsewhere worked out by streams. Such valleys are not uncommon in the chalk downs, especially to the south of the Thames valley. Green turf often covers bed and sides, and they resemble in general outline those down which water still runs. Not seldom, however, after descending one of these for some distance from its head, we come to a stream, taking its rise from one or more springs, which, in certain cases, only run for part of the year. Such intermittent streams generally go by the name of bournes, but they may be regarded

as a local accident rather than as calling for an explanation altogether different from that of the ordinary dry valley. It is now generally agreed that both the one and the other admit of the following explanation. The first beginning of the valley must be carried back to a time when the mean temperature was lower and the vegetation in the neighbourhood much more scanty than it is at the present day. Then the ground might be frozen, either permanently or during a considerable part of the year, to a depth of a few feet. This would prevent the percolation of water from rain and melting snow, and compel it all to run off above ground, when it would produce the usual effects. Thus these valleys were the work of rain and streams, but under conditions different from those which now prevail. In addition to this, when the mean temperature became higher and this icy crust no longer formed, the level of underground saturation in a porous rock would be higher, so that, if other circumstances were favourable, springs might break out farther up the beds of the valleys than at the present day. But as the climate approached its present normal, and the saturation level sank, the springs, or the upper of them, if more than one set existed, would cease to run. Thus, in one place a valley may now be entirely dry, in another it may pass from this state after a wet season to one watered in the usual way, while in a third, when the level of

the saturation surface temporarily rises above that of the valley floor, a spring may break out of the ground, and flow from one of the ancient outlets, forming a bourne.

In Hertfordshire there is a well-known bourne near Berkhamstead, which only runs after an exceptionally rainy season, usually beginning early in the spring and ceasing in the summer. According to Mr J. Hopkinson[1] it is recorded to have flowed twelve times in the interval between 1852 and 1904, and this has occurred when the rainfall for the year, ending on March 31, has not been less than thirty inches, and for half a century it has only twice failed to make its appearance, when this quantity has been measured.

But dry valleys with a bolder outline are rather common in districts where a limestone, such as that called the Carboniferous, attains a considerable thickness. We have only to study the noted Cheddar cliffs in Somersetshire to see that they have been carved out by a stream which has now disappeared (fig. 14). From the village of that name, at the foot of the Mendips, a glen runs up into the hill district. Though of no great extent, it is comparable "with some of the finest glens in Derbyshire. The cliffs rise on the one hand in absolute precipices, on the other they

[1] *Geology in the Field* (*Middlesex and Hertfordshire*), p. 11.

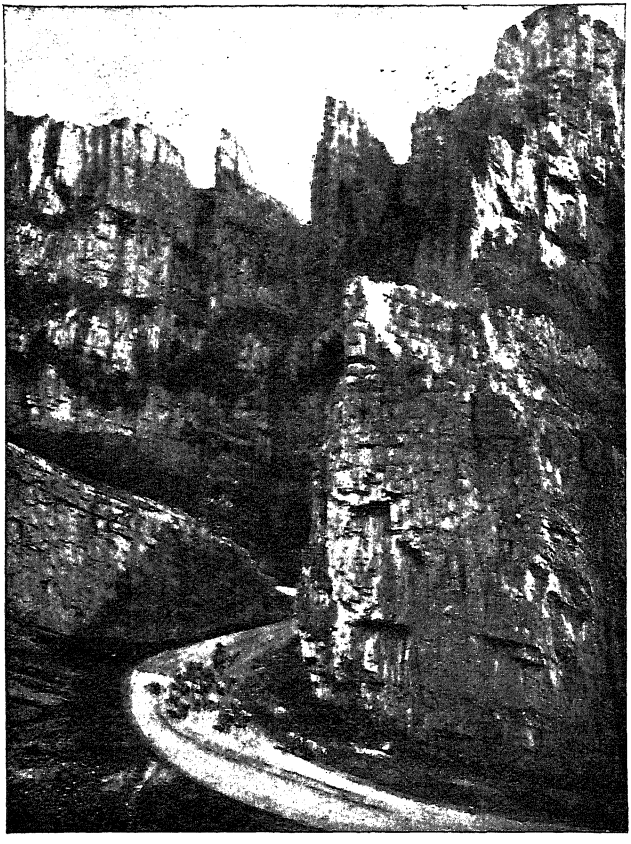


Fig. 14. Cheddar Cliffs.

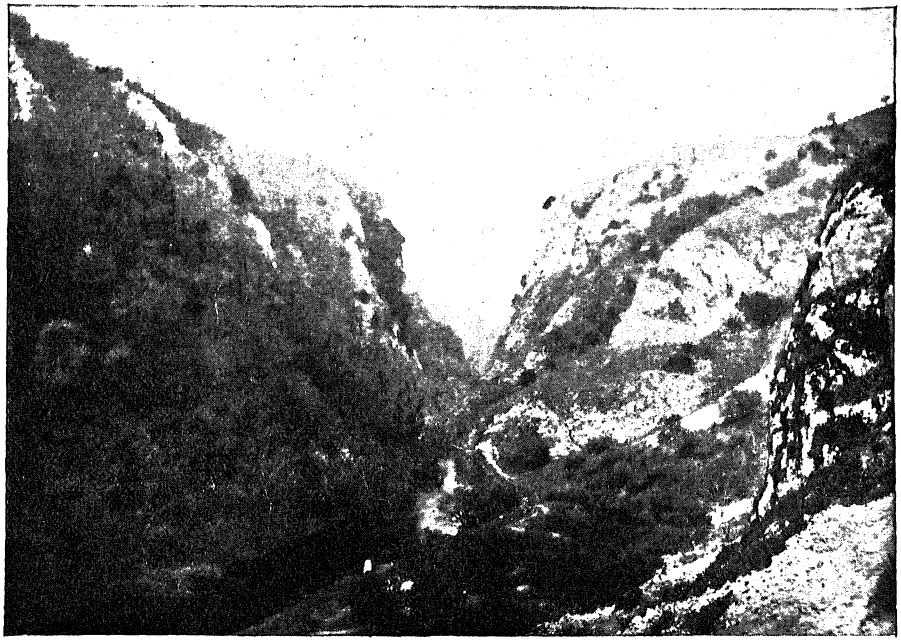


Fig. 15. Dovedale from Reynard's Cave.

and left off the sawing of a glen, in order to dig out a line of caves.

When rivers pass from a hilly to a lowland region, their courses widen, their banks become lower and their windings increase. They now flow over a very gentle slope; their velocity diminishes, they gradually become incapable, under ordinary circumstances, of deepening their channel, and at last, as we shall presently see, deposit much of the material which they have been transporting. Their courses to these regions accord with two empiric laws, enunciated about half a century ago by the late James Fergusson[1]. These are (1) the extent of the curve is proportional to the volume of the stream; and (2) the radius of curvature is proportional to the slope. When the fall is ten feet in a mile, the curve is almost a straight line: when it is three inches, that becomes nearly a semicircle. With such a curve the chord is about four times the width of the stream. With a fall between six inches and one foot the stream oscillates once in six times its width; when it is more than a foot the oscillation is once in ten or twelve times the width. In other words big rivers, when they flow slowly, make big curves, and little rivers, little curves. Proofs of the latter rule are common in our own country, wherever a stream

[1] *Quart. Journ. Geol. Soc.* XIX. (1863), p. 322.

remains intact. A brook may be seen wriggling like a snake through the meadows of a flat-bottomed valley, and as its volume increases, so does the magnitude of its curves. The Thames, for instance, upstream above Battersea makes one long sweep round Fulham, another, in the opposite direction, round Barnes Common, a third round Chiswick, yet another, slightly more complex, round Kew and Richmond, and behaves in the same way higher up from Twickenham.

The quicker the flow of a stream the straighter its course and the greater its downward as compared with its sideward action. A differential elevation of the land, which increases with the distance from the coast, or a greater rainfall in the same direction, will produce a quicker flow and diminish the winding of a channel, while a change in the opposite direction will have a contrary effect. The flat bed of an English river-valley sometimes preserves, at a slightly higher level than the present winding stream, a fragment of a straighter course. The alteration might be caused by a change of level, but is more probably due to the fact that when the average temperature was lower than now, melting snow and a heavier rainfall made the rivers larger and their courses straighter. The strength of the excavating tools, as a further study of valley structure will demonstrate, has been liable to variation.

Nowhere is this more clear than in the cañon district of Colorado, which has been so admirably illustrated and described by the United States Geological Survey. A vast plateau extends from near the base of the Rocky Mountains to the head of the Gulf of California. Through this the river has cut a channel, nearly 500 miles in length, the bed of which is from 3000 to 6000 feet below the surface level. The plateau consists of a thick group of sedimentary rocks, resting on a solid floor of granite, which are of various ages, Palaeozoic, later Mesozoic and earlier Kainozoic. In the grandest part the section is chiefly cut through strata of Carboniferous and Permian age. The bedding is practically horizontal, and harder alternate with softer deposits. Two distinct phases are manifest in the history of the valley. The upper part, perhaps 1000 feet deep, is a broad trench with steep walls of alternating crag and slope, their edges occasionally notched by short ravines. Near to these insulated masses rises here and there from the bed of the trench, like outlying forts, remnants of once continuous material, which has been swept away. In the floor of this trench another valley has been cut, narrower, deeper and even steeper, but in its main characteristics similar to the other and older one. Cliffs, some 3000 feet in height, descend to the river, which generally washes their base on either side. The brink of these also is occasionally notched, or a

bastion tower may stand slightly in advance of the main central wall. One of these cañons would be an ideal boundary for any country, since it makes a more effective barrier than most mountain regions or a narrow sea. A hunter on one side might kill with his rifle a deer on the other, and spend some days before he could reach the venison.

Three or four favourable conditions must coincide before one of these cañons can be formed: (1) The existence of a plateau composed either of a thick mass of a uniform hard rock, or of alternating strata, which though differing somewhat in their power of resisting denudation are not readily destroyed. (2) A strong and rapid river making its way downwards over the plateau. (3) On this, however, the rainfall must be small, for otherwise the cliffs would be too much breached by the drainage from either side. In other words the cañon region must itself be arid, but there must be a considerable rainfall on that from which its rivers are supplied. But the Colorado cañon requires another condition: its first stage was a valley, about six miles wide. The stream, which excavated this, though powerful, must have flowed more slowly than the present river, for, as we can hardly suppose it to have occupied the whole breadth of the valley, except perhaps during floods, it must to some extent have wandered from side to side. Then something happened to quicken its pace: probably the

whole region began to rise, and this not quite uniformly, but with a slight upward tilt inland. This movement might also slightly affect the rainfall, increasing it on the mountainous zone and diminishing it on the table-land[1]. In any case the cutting power of the river was increased, and that, as we may infer, from the sharp definition of the lower gorge, rather suddenly. But after this had happened the rise probably continued, slowly and steadily, so that the conditions of erosion remained practically uniform for a very long time[2].

The erosive action of running water is commonly gradual and continuous, though of course it is always intensified in time of flood (fig. 16). But it is impeded by vegetation which, on the gentler slopes, may largely neutralize the effect of rain: the blades of grass and other herbage, like little shields, break the force of the falling drops; their roots bind the soil together and save it from being washed away. But a single storm in arid regions, sudden and violent, such as sometimes occurs, may produce more effect than years

[1] This would require that the dominant winds should blow seawards as is the case on western coasts of continents in the tradewind zone.

[2] For illustrations and particulars see T. C. Chamberlin and R. D. Salisbury, *Geology, Processes and their Results* (1905), pp. 91–95, A. Geikie, *Text-book of Geology* (1903), Frontispiece and pp. 504, 1382, and C. E. Dutton in *The Second Annual Reports of the U.S. Geol. Survey*, p. 49.